



Estimation of Forest Biomass for Quantifying CO₂ Emissions in Central Kalimantan:

*A comprehensive approach in determining
forest carbon emission factors*



Ministry of Forestry
Forestry Research and Development Agency
Research and Development Center for Conservation and Rehabilitation

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Authors:

Haruni Krisnawati
Wahyu Catur Adinugroho
Rinaldi Imanuddin
Silver Hutabarat

Reviewers:

Robert Waterworth
Michael Parsons
Adi Susmianto

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Email: p3hka_pp@yahoo.co.id; website: <http://puskonser.or.id>

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The Government of Indonesia has committed to reducing greenhouse gas (GHG) emissions by 26% below business as usual levels by 2020 independently and up to 41% with international assistance. Many activities are underway at both the local and national levels to help meet this commitment. REDD+ is one policy instrument with strong potential to help tackle the climate change and reduce GHG emissions through avoided deforestation and forest degradation, forest conservation, management of natural forests, and the enhancement of forest carbon stocks.

An essential component to all GHG emissions reduction activities is having a credible and transparent MRV (Measurement, Reporting, Verification) system. The *Indonesian National Carbon Accounting System* (INCAS) is a Government of Indonesia system designed to support Indonesia's emissions reporting requirements for forests, including MRV for REDD+. It is currently being supported by the Indonesia-Australia Forest Carbon Partnership (IAFCP), with funding and technical advice provided by the Government of Australia.

In developing an MRV for REDD+, a fundamental input is tools to estimate forest biomass, forest carbon stocks and carbon uptake as a result of forest change. Considering the diversity of forests in Indonesia, the development of reference emissions levels that are specific to local conditions is essential.

This report presents an analysis of forest biomass estimations in Central Kalimantan (as the first REDD+ pilot province in Indonesia) using a comprehensive approach. This report has been prepared by the INCAS team in FORDA (Forestry Research and Development Agency), using several sources of forest inventory data from various institutions under Ministry of Forestry (Directorate General of Forestry Planning, Directorate General of Forestry Production Development, Forestry Research and Development Agency, and the REDD+ pilot project of the Kalimantan Forests and Climate Partnership), and other sources of data including research studies. The methods and analysis used in this report are also relevant and replicable to other provinces and at the national level, and are able to support the development of a credible MRV system.

We would like to express our appreciation to related parties who have contributed directly or indirectly to the preparation of this report. Thank you to the IAFCP for facilitating discussions, reviewing the results, and funding the publication of this reserach. Special thanks to the Authors – researchers of the Research and Development Center for Conservation and Rehabilitation and INCAS Team, we express our appreciation for their hardwork and congratulations on this achievement.

I hope this report serves a useful source of information for related activities.

Bogor, February 2014

Acting Director General,

Forestry Research and Development Agency



Dr.Ir. I.B. Putera Parthama, M.Sc

Abstract

This study provides a comprehensive assessment of forest biomass and carbon stocks for natural forests in Central Kalimantan. Total forest biomass estimates are presented for three main natural forest types (dryland, swamp and mangrove forests) with two different conditions (primary and secondary forests). These values quantify initial forest biomass conditions for modeling greenhouse gas (GHG) emissions and removals, as used in the Indonesian National Carbon Accounting System (INCAS), or to calculate CO₂ emission factors for quantifying GHG emissions due to forest clearing or deforestation in Central Kalimantan. Several sources of forest inventory data and information available from previous study were used in estimating forest biomass. This result provides an improved and more comprehensive analysis of emissions factors for forests by using Central Kalimantan-based forest inventory plots and allometric guidelines for quantifying forest biomass and forest carbon content. In addition, it includes all components of aboveground biomass of forest ecosystem. Further research is needed to relate forest biomass and carbon stocks to other determining factors such as forest type, soil type and climate, as well as the proportions of biomass immediately emitted due to forest management activities and the portion of biomass decomposed over specified time intervals.

Keywords: forest type, biomass estimation, carbon accounting, emission factor

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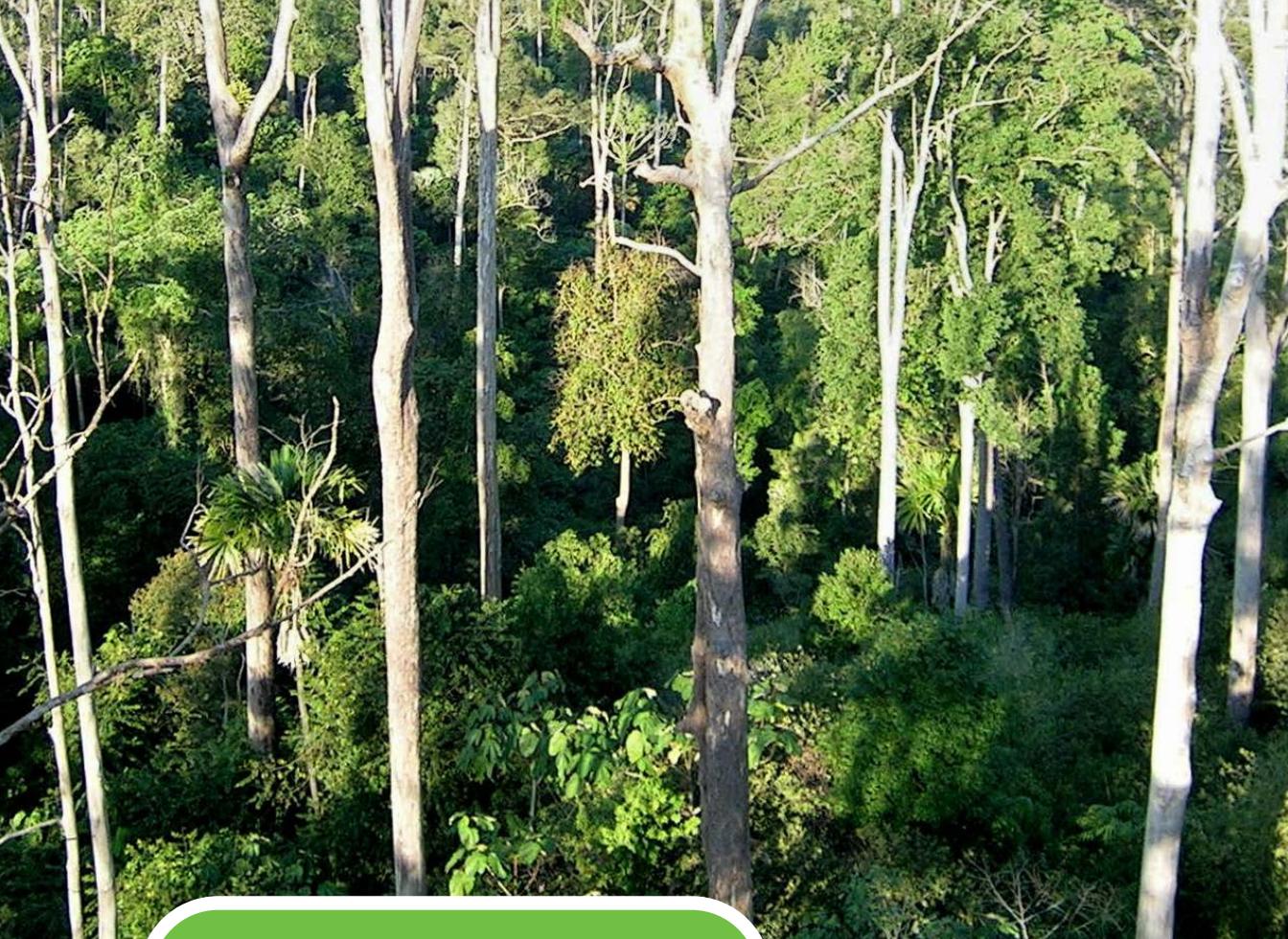
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1. Introduction

The Indonesian National Carbon Accounting System (INCAS) is being developed to support the Indonesian Government's greenhouse gases (GHG) emissions reporting requirements from the land sector, including MRV (Measurement, Reporting, and Verification) for REDD+ (reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forest and enhancement of forest carbon stocks), and the generation of national GHG inventories. The INCAS is being developed to account for emissions and removals of GHGs to and from the atmosphere from land use changes and forest management activities in Indonesia. The INCAS will be an integrated system using both remote sensing and ground-based measurements to quantify GHG emissions and assess performance against emissions reduction targets.

One approach to account for GHG emissions is to estimate forest carbon stocks under different forest conditions across forest types. The amount of carbon stored and subsequently emitted to the atmosphere varies greatly depending on forest conditions (Gibbs et al, 2007). The main carbon pools in forest ecosystems are the living biomass, the dead organic matter and soil organic matter.

A credible approach to accounting for changes in biomass and carbon stocks for reporting GHG emissions from forests is to consider all relevant carbon pools including aboveground biomass, roots (belowground biomass), dead organic matter (litter, woody debris), and soil organic matter;

and the flow between them as a result of observable disturbance. Since carbon moves from one pool to another pool in the ecosystem, integration of data over all pools is required for a comprehensive inventory of GHG emissions. Each pool has the potential to be either a source or sink of GHGs.

Central Kalimantan is the first pilot province for REDD+ implementation in Indonesia. The estimated area of natural forest lands in Central Kalimantan (based on the Ministry of Forestry's 2011 land cover map) is around 8 million ha consisting of three main categories (types) of natural forests: dryland forest (71.9%), swamp forest (27.8%), and a small area of mangrove forest (0.3%). These three forest types have different characteristics in species and environmental conditions. Some areas of each forest type have been disturbed (being secondary forests) which results in less carbon stored in forest biomass compared with undisturbed (primary) forest condition. These categories need to be considered when quantifying forest biomass for monitoring and reporting GHGs.

Comprehensive estimates of stock and changes in forest carbon pools have not been widely available in Indonesia. Forest inventory data from both temporary and permanent sample plots can be used to provide a sound basis for estimating carbon stocks and changes associated with land use changes and forest management activities. The objectives of this paper are: (1) to develop a methodology for estimating total forest biomass based on inventory plot data available for Central Kalimantan and other locally collected information from literature or previous studies; (2) to use these data for quantifying carbon pools based on forest type in primary and secondary forest conditions (including aboveground biomass, belowground biomass, litter and woody debris but excluding soil organic matter); and (3) to provide the average estimates of carbon for each forest type and forest condition that can be used to estimate GHG emissions and removals in climate mitigation initiatives.



2. Selected Methodology

2.1 Overall Approach

Estimates of forest biomass and carbon stocks were developed for the major natural forest types in Central Kalimantan based on the classification of natural forests included in the Ministry of Forestry's land cover map (i.e. primary dryland forest, secondary dryland forest, primary swamp forest, secondary swamp forest, primary mangrove forest, and secondary mangrove forest).

For each of these forest types, representative quantities of aboveground biomass, belowground biomass, mass of litter and woody debris were derived from available data. Soil organic matter was not included in this analysis; but it is critical to consider, particularly on peat swamp forest where soils may be a large ongoing source of carbon emissions following disturbance. (This analysis will be discussed in a separate paper).

Figure 1 provides an overview of the approach used to quantify forest biomass and carbon in each pool for Central Kalimantan forest.

Data used in the analysis come from several sources of forest inventory plots available for Central Kalimantan and additional information taken from the literature. The aboveground biomass of individual trees in the plots was estimated using allometric models developed for specific

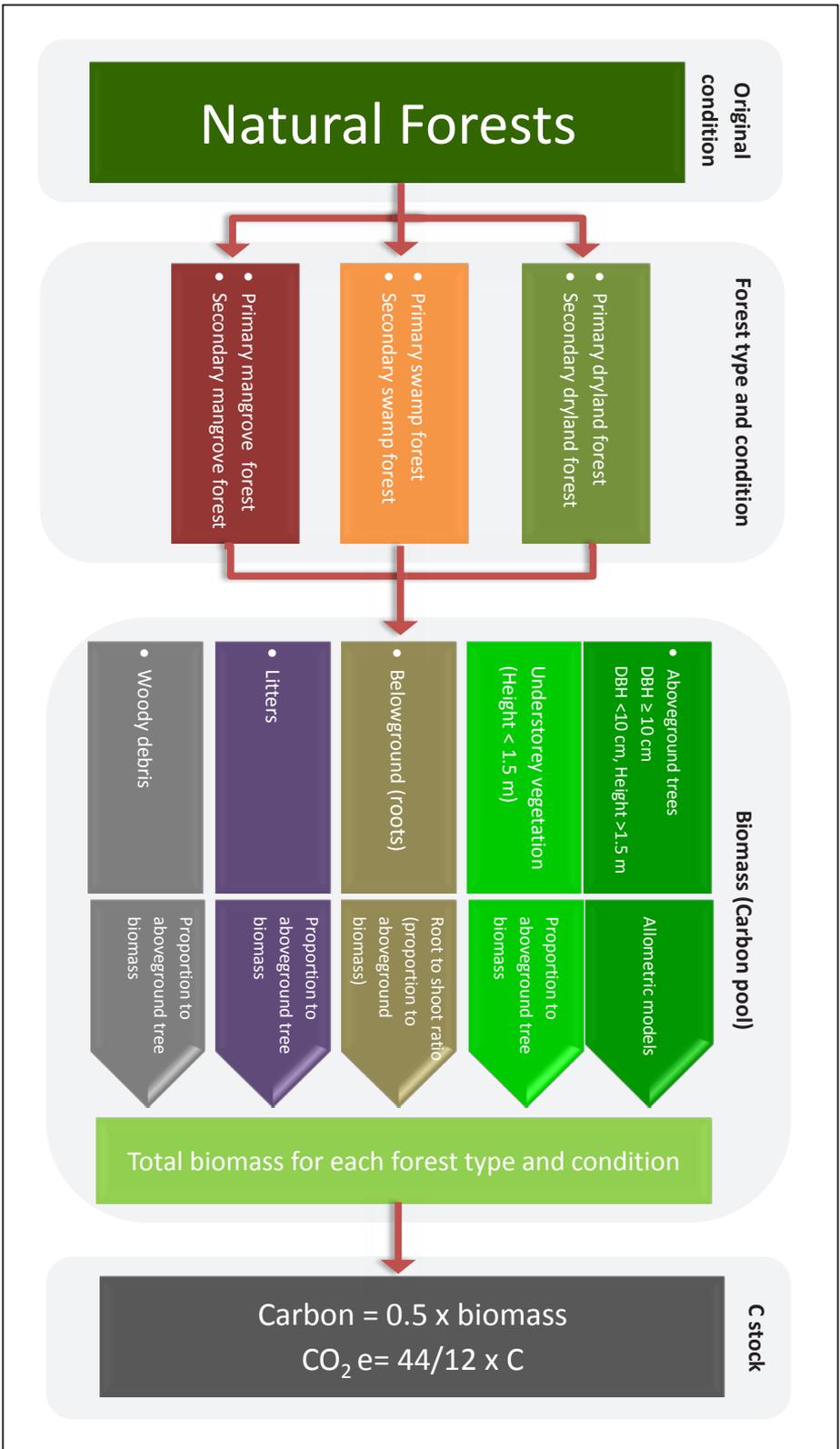


Figure 1. Overview of the approach used to quantify forest biomass and carbon stocks in each pool for Central Kalimantan natural forests

sites in Kalimantan. Carbon pools not measured in the forest inventories were estimated using relationships with aboveground tree biomass established in previous studies in Kalimantan or elsewhere in Indonesia, and other locally collected information and literature.

The detailed descriptions of the data used and the methodology applied are described below.

2.2 Data Description

Several sources of forest inventory data managed by the institutions within the Ministry of Forestry were used to estimate biomass and carbon stock. This included data from the National Forest Inventory (NFI), Periodical Comprehensive Forest Inventory (PCFI) and Permanent Measurement Plots (PMP) established in Central Kalimantan. Additional forest inventory data from vegetation monitoring plots in the Kalimantan Forests and Climate Partnership (KFCP) project site in Central Kalimantan were included. A description of these plots is provided in Annex 1. Of the 10,231 inventory plots available, the quality assurance process reduced the usable number of plots to 6,466 for analysis. Information from these plots was examined and data were checked as part of the INCAS quality assurance process. The spatial distribution of inventory plots across Central Kalimantan included in the analysis is provided in Figure 2. These inventory plots were mainly established in dryland forest and swamp forest.

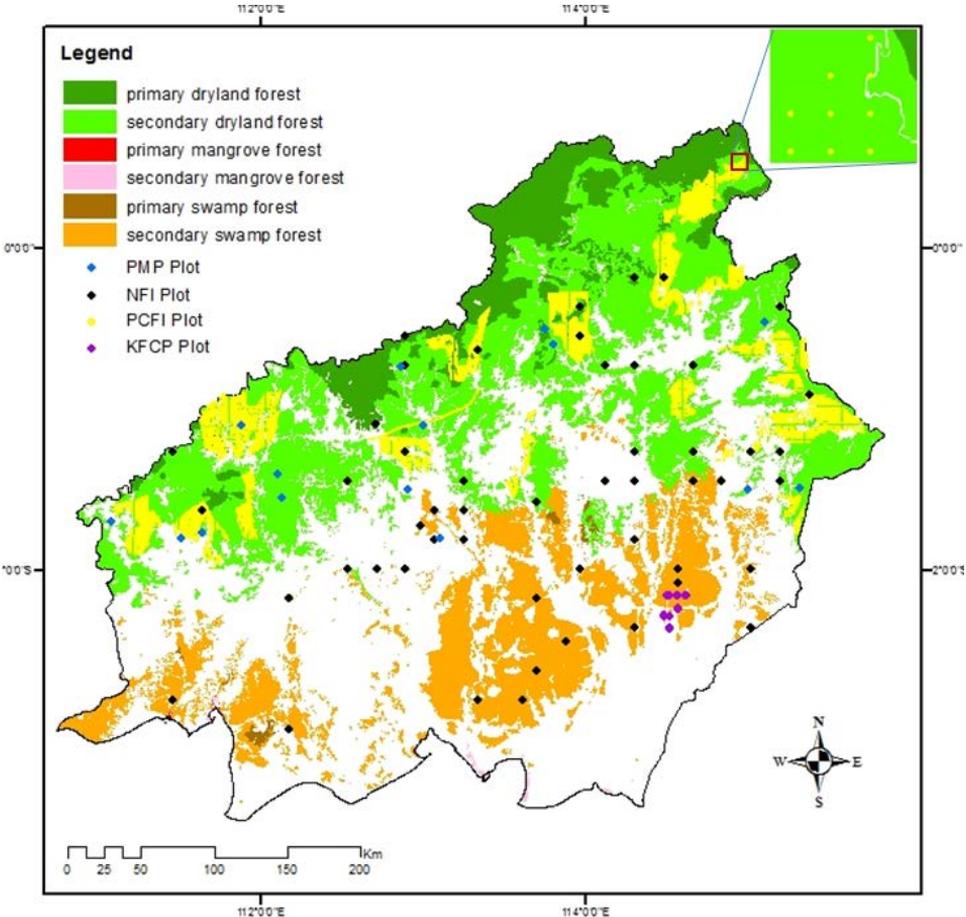


Figure 2. Spatial distribution of the inventory plots in Central Kalimantan used for analysis

As inventory plots from different sources were established for different purposes (see Annex 1), there is no standardized protocol of data collection (e.g. sampling design, plot size, coverage of measurement data, etc). All the inventory plots share the following similar measurement standards: (1) located in forests with a total area inventoried of at least ≥ 0.1 ha; (2) all trees of at least ≥ 10 cm diameter at breast height (DBH) were measured for DBH, and (3) the species for measured trees were identified. In addition, information related to the plot location was also recorded including: (1) administrative location (province, district, sub-district), (2) geographical position (longitudinal and latitudinal coordinates), (3) forest type, (4) climatic condition (rainfall, temperature), (5) soil type, and (6) topographical condition. Accuracy of this information was checked further by overlaying with relevant maps.

Summary statistics of the data from various sources of forest inventory plots used for analysis in this study are presented in Table 1.

Table 1. Summary statistics of data from various sources of forest inventory plots in Central Kalimantan used for analysis in this study.

Source of data	Forest type covered	Number of plots used	Plot size (ha)	Minimum DBH measured
NFI	PDF, SDF, PSF, SSF	65	1	5 cm
PCFI	PDF, SDF, SSF	5942	0.25	10 cm
PMP	SDF	421	1	10 cm
KFCP	PSF, SSF	38	0.1	< 5 cm, H > 1.5 m

Notes:

- PDF: Primary Dryland Forest; SDF: Secondary Dryland Forest; PSF: Primary Swamp Forest; SSF: Secondary Swamp Forest
- None of the inventory plots were established in either primary or secondary mangrove forests

To estimate forest biomass in other pools such as understory vegetation, roots, litters and woody debris; requires the use of forest data from research studies. Forest inventory plots generally capture information on trees only; information available from biomass and/or carbon related studies reported in research papers was assessed to fill information gaps not covered in the forest inventories, e.g. other biomass components such as understory vegetation, belowground tree biomass (roots), litter, and woody debris. None of the forest inventory plot network available in Central Kalimantan was established in either primary or secondary mangrove forest (Table 1). Instead, information from previous studies on ecosystem carbon assessments conducted in Kalimantan mangrove forests (e.g. Murdiyarso et al., 2009; Krisnawati et al., 2012) was used.

2.3 Estimating Aboveground Biomass (AGB)

Aboveground biomass (AGB) includes all trees and understory vegetation. Data for all individual trees in the inventory plots (Table 1) were used to estimate AGB. In some plots (i.e. PCFI and PMP), the trees were measured when the diameter at breast height (DBH) was 10 cm or larger, while for some of the other plots the minimum diameter of trees measured were smaller (e.g. DBH ≥ 5 cm for NFI plots; DBH < 5 cm and height > 1.5 m for KFCP plots).

2.3.1. AGB for trees (DBH ≥ 10 cm)

The AGB of individual trees (DBH ≥ 10 cm) was estimated using allometric models developed for specific sites in Kalimantan, following the monograph on allometrics (Krisnawati et al.,

2012) and the guideline on the use of allometric models for estimating forest biomass and carbon stocks in Indonesia (FORDA, 2013). The models were derived from destructively sampled trees (direct measurement) and easily measured biometric variables such as diameter (DBH). The resulting AGB is the total AGB of the tree (including stem, branches, twigs, leaves and fruit/flowers if any) in dry weight (expressed in kilograms (kg)).

The total aboveground tree biomass for each plot was then quantified by summing aboveground biomass estimates for all trees on the plots in dry weight (expressed in Megagrams (Mg) or tonnes (t)).

$$AGB_p = \sum_1^n AGB_t / A_p$$

where AGB_p = aboveground biomass of plot (kg ha^{-1}), or expressed as (Mg ha^{-1}) or (t ha^{-1}) after multiplying with a conversion factor of 0.001, AGB_t = aboveground biomass of measured tree (kg), A_p = plot area (ha), n = number of trees per plot.

2.3.2. AGB for trees (DBH < 10 cm; height > 1.5 m)

The AGB of trees with DBH < 10 cm and height > 1.5 m was estimated using the same procedure applied for estimating AGB for trees with DBH \geq 10 cm.

For inventory plots where the presence of trees with DBH < 10 cm was not included (e.g. PCFI, PMP), the proportion derived from the plots having a complete pool of aboveground tree components was used and then the average proportion for the unmeasured component in the plots was applied. For example, the average proportion of AGB for trees with DBH < 10 cm; height > 1.5 m (derived from KFCP plots data) to AGB for trees with DBH \geq 10 cm was used to quantify the unmeasured component of aboveground tree biomass (DBH < 10 cm; height > 1.5 m) for swamp forests. The resulting proportions were 44.4% for primary and 48.1% for secondary swamp forests, respectively.

For dryland forests, the average proportion of AGB for trees with $5 \text{ cm} \leq \text{DBH} < 10 \text{ cm}$; height > 1.5 m to AGB for trees with DBH \geq 10 cm (derived from NFI plots) was used to quantify the unmeasured component of aboveground tree biomass ($5 \text{ cm} \leq \text{DBH} < 10 \text{ cm}$; height > 1.5 m). For primary and secondary dryland forests the resulting proportions were 7.2% and 4.5%, respectively.

For the other unmeasured components of AGB for trees with DBH < 5 cm; height > 1.5 m, proportions of 0.2% for primary dryland forest and 1.1% for secondary dryland forests were adopted from a previous study in dryland protection forest in West Nusa Tenggara (Krisnawati et al., 2013).

2.3.3. AGB for understory vegetation (height < 1.5 m)

All inventory plots provide only aboveground tree components; understory vegetation (including seedlings, shrubs, vines, herbaceous plants, etc.), which are part of aboveground biomass in forest ecosystems, were not included. The contribution of this component to AGB varies, but is generally small (Brown and Lugo, 1992; Tanner, 1980). Regardless, this component has been included in the analysis to provide complete estimates of total aboveground biomass of forest.

Aboveground biomass for understorey vegetation was estimated using a proportion based on the results of previous studies considering the forest ecosystem type. For swamp forests, the average proportion was applied derived from several studies conducted in Central Kalimantan (Jaya et al, 2007; Dharmawan, 2012), resulting in estimates of understorey vegetation biomass of 2.4% of aboveground tree biomass for primary swamp forest, and 3.8% for secondary swamp forest. For secondary dryland forests, the proportion of 2.7% of aboveground tree biomass was derived from the studies of Junaedi (2007) and Hardiasyah (2011) conducted in Central Kalimantan. As no known studies have been conducted for primary dryland forest anywhere in Kalimantan, the proportion 0.5% of aboveground tree biomass was adopted from a previous study in dryland protection forest in West Nusa Tenggara (Krisnawati et al., 2013).

2.4. Estimating Belowground Biomass (Roots)

The estimates of belowground biomass (roots) can be derived from an allometric model or as a proportion of aboveground biomass/root-to-shoot ratio (IPCC 2003). The default value for the root-to-shoot ratio of the tree biomass has been published in the Good Practice Guidance for LULUCF (Land Use, Land Use Change and Forestry) and in the REDD sourcebook, i.e. 0.24 (0.22-0.33) (IPCC 2003; GOF-C-GOLD, 2009). However, the ratio may vary according to species, ecosystem type, soil and climatic condition. In this study, the root-to-shoot ratio of 0.29 was adopted derived by Moser (2011) in tropical dryland forests. For swamp forest, an allometric model developed by Niyama et al. (2005) was first applied to estimate belowground biomass for each plot having a complete measurement of aboveground tree component (e.g. KFCP data), and the average proportion of belowground biomass to aboveground biomass was obtained resulting in a root-to-shoot ratio of 0.22.

2.5 Estimating Litter

Litter consists of remaining dead plant material (fruits, leaves, flowers) on the forest floor. Estimation of litter biomass is particularly difficult as it is highly variable and dynamically related to forest productivity and disturbance history. The amount of litter biomass has been reported to vary from 1.3% to 23.6% of aboveground tree biomass (Brown et al., 1995; Delaney, 1997; Nascimento and Laurance, 2002; Jaya et al., 2007; Hardiasyah, 2011; Dharmawan, 2012). In this study, 3.0% was used for primary dryland forest; 3.5% for secondary dryland forest (Hardiasyah, 2011; Brown et al., 1995); 1.6% was used for primary swamp forest, and 2.3% for secondary swamp forest (Jaya et al., 2007; Dharmawan, 2012).

2.6 Estimating Woody Debris

Woody debris consists of all dead woody materials including standing dead trees, fallen trees, and part of trees (stem, branch, twig) on the ground. Similar to litter, estimation of biomass contained in woody debris is difficult; it is highly variable and dynamically related to forest productivity and disturbance history (particularly burning and harvesting).

Woody debris may be a significant component in some tropical forest types, particularly in secondary forest following disturbance. This pool may constitute 10-40% of aboveground biomass (Uhl and Kauffman, 1990; Verwer and Van der Meer, 2010). In this study, biomass contained in

woody debris was estimated to be 18% of aboveground tree biomass for primary dryland forest (an average proportion derived from Delaney et al., 1998; Gale, 2000; Clark et al., 2002; Chambers et al., 2004; Keller et al., 2004; Rice et al., 2004; Yoneda et al., 2004; Brown et al., 2005; Palace et al., 2008; Pyle et al., 2008), and 33% for secondary dryland forest (Clark et al., 2002; Rice et al., 2004). For peat swamp forest, a proportion of 18.5% of AGB was used to estimate biomass in woody debris for primary swamp forest (Dharmawan, 2012), and 23.9% for secondary swamp forest (Ludang and Jaya, 2007; Dharmawan, 2012).

2.7 Estimating Total Biomass and Carbon Stocks

Estimates of total biomass for each plot was quantified by summing aboveground tree biomass (DBH \geq 10cm), aboveground tree biomass (DBH < 10 cm, H > 1.5 m), aboveground biomass of understorey vegetation (H < 1.5 m), belowground biomass (roots), and mass of litter and woody debris.

$$\text{Total biomass} = \text{AGB}_{(\text{DBH} \geq 10\text{cm})} + \text{AGB}_{(\text{DBH} < 10\text{cm}; \text{H} > 1.5\text{m})} + \text{AGB}_{\text{understorey (H} < 1.5\text{m})} + \text{BGB} + \text{L} + \text{WD}$$

where $\text{AGB}_{(\text{DBH} \geq 10\text{cm})}$ = aboveground biomass of trees with DBH \geq 10 cm; $\text{AGB}_{(\text{DBH} < 10\text{cm}; \text{H} > 1.5\text{m})}$ = aboveground biomass of trees with DBH < 10 cm and height > 1.5 m; $\text{AGB}_{\text{understorey (H} < 1.5\text{m})}$ = aboveground biomass of understorey vegetation (height < 1.5 m); BGB = belowground biomass (roots); L = biomass of litter; WD = biomass of woody debris.

The quantity of biomass (stored in aboveground trees, understorey vegetation, litter, woody debris, and roots) in a forest determines the potential amount of carbon that is stored and could be released to the atmosphere due to clearing/deforestation and conversion to non-forest land use. To estimate the amount of carbon in each component of each forest type, information on carbon fraction is needed. The carbon fraction of biomass (dry weight) was assumed to be 50% (1 Mg biomass = 0.5 Mg C) (Clark et al., 2001; Malhi et al., 2004). Conversion of C-stock into carbon dioxide equivalent (CO₂-e) can then be obtained by multiplying C-stock with a factor of (44/12).



3. Results

3.1. Total Biomass in Each Forest Type

Tables 2 and 3 provide a summary of total biomass estimates for primary dryland forest and secondary dryland forest in Central Kalimantan.

Table 2. The estimates of total dry biomass in primary dryland forest

Carbon Pool	Mean (Mg ha ⁻¹)	95% Confidence Interval (Mg ha ⁻¹)	
Aboveground Biomass	298.2	283.0	313.4
Trees	296.8	281.8	312.0
<i>DBH ≥ 10 cm</i>	276.4	262.4	291.0
<i>5 cm ≤ DBH < 10 cm</i>	19.8	18.8	20.8
<i>DBH < 5 cm (Height > 1.5 m)</i>	0.6	0.6	0.6
Understorey (Height < 1.5 m)	1.3	1.3	1.4
Belowground Biomass (Roots)	86.5	82.1	90.8
Litters	9.0	8.5	9.5
Woody Debris	49.9	47.4	52.5
Total Forest Biomass	443.6	421.0	466.1

Note: Number of inventory plots used for analyzing aboveground tree biomass: 373 plots

Table 3. The estimates of total dry biomass in secondary dryland forest

Carbon Pool	Mean (Mg ha ⁻¹)	95% Confidence Interval (Mg ha ⁻¹)	
Aboveground Biomass	218.2	216.0	220.5
Trees	212.4	210.3	214.6
<i>DBH ≥ 10 cm</i>	201.0	198.9	203.0
<i>5 cm ≤ DBH < 10 cm</i>	9.1	9.0	9.2
<i>DBH < 5 cm (Height > 1.5 m)</i>	2.4	2.4	2.4
Understorey (Height < 1.5 m)	5.8	5.7	5.9
Belowground Biomass (Roots)	63.3	62.6	63.9
Litters	7.4	7.4	7.5
Woody Debris	66.3	65.6	67.0
Total Forest Biomass	355.3	351.6	358.9

Note: Number of inventory plots used for analyzing aboveground tree biomass: 4,686 plots

Tables 4 and 5 provide a summary of total biomass estimates for primary swamp forest and secondary swamp forest in Central Kalimantan.

Table 4. The estimates of total dry biomass in primary swamp forest

Carbon Pool	Mean (Mg ha ⁻¹)	95% Confidence Interval (Mg ha ⁻¹)	
Aboveground Biomass	221.3	191.7	250.9
Trees	216.2	187.3	245.2
<i>DBH ≥ 10 cm</i>	149.7	129.7	169.8
<i>DBH < 10 cm (Height > 1.5 m)</i>	66.5	57.6	75.4
Understorey (Height < 1.5 m)	5.1	4.4	5.8
Belowground Biomass (Roots)	48.7	42.2	55.2
Litters	3.5	3.0	3.9
Woody Debris	40.0	34.7	45.4
Total Forest Biomass	313.5	271.5	355.4

Note: Number of inventory plots used for analyzing aboveground tree biomass: 42 plots

Table 5. The estimates of total dry biomass in secondary swamp forest

Carbon Pool	Mean (Mg ha ⁻¹)	95% Confidence Interval (Mg ha ⁻¹)	
Aboveground Biomass	190.1	187.4	192.9
Trees	183.1	180.5	185.8
<i>DBH ≥ 10 cm</i>	123.6	121.8	125.4
<i>DBH < 10 cm (Height > 1.5 m)</i>	59.5	58.6	60.4
Understorey (Height < 1.5 m)	7.0	6.9	7.1
Belowground Biomass (Roots)	41.8	41.2	42.4
Litter	4.3	4.2	4.3
Woody Debris	43.8	43.1	44.4
Total Forest Biomass	280.0	275.9	284.0

Note: Number of inventory plots used for analyzing aboveground tree biomass: 1,365 plots

Table 6 provides a summary of total biomass estimates for both primary and secondary mangrove forests in Central Kalimantan.

Table 6. The estimates of total dry biomass in primary and secondary mangrove forests

Carbon Pool	Mean (Mg ha ⁻¹)	
	PMF	SMF
Aboveground Biomass (DBH ≥ 5cm)	208.5	124.7
Belowground Biomass (Roots)	15.1	14.8
Woody Debris	99.7	93.3
Litter	nd	nd
Total Forest Biomass	323.3	232.8

Notes:

- Estimates for PMF (primary mangrove forest) derived from studies by Murdiyarso et al. (2009) and Krisnawati et al. (2012); estimates for SMF (secondary mangrove forest) derived from a study by Krisnawati et al. (2012)
- nd (no data): Litter was not included as most mangroves have little to no litter, contributing negligible carbon pool (Snedaker and Lahmann, 1988).

3.2 Proportion of Carbon in Each Forest Carbon Pool

Figure 3 shows the proportion of carbon in forest carbon pools for each forest type.

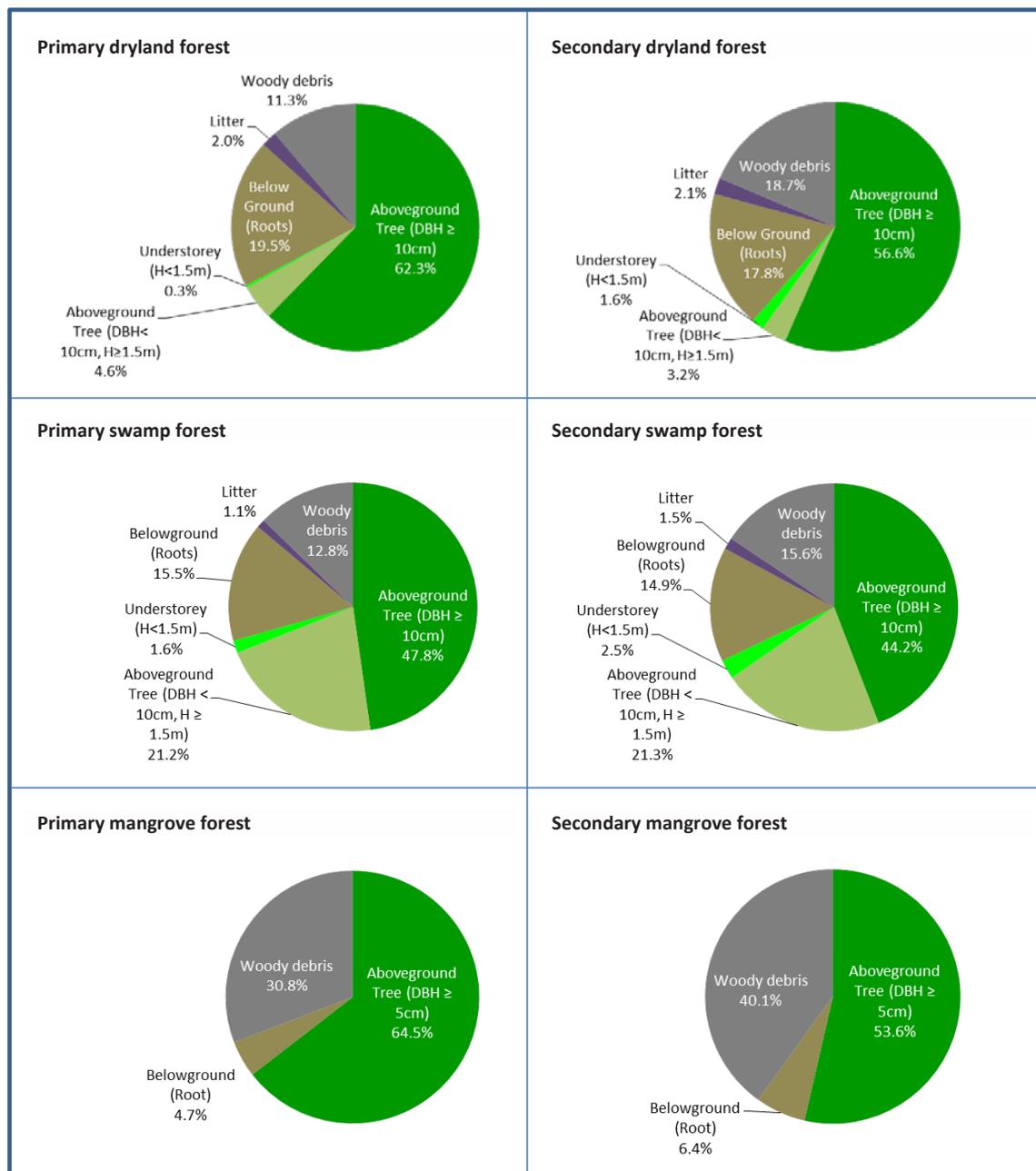


Figure 3. Proportion of carbon stored in forest carbon pools

3.3 Summary of Carbon Stock in Each Forest Type

Table 7 provides a summary of the carbon content of the average biomass in each forest type for the purpose of carbon accounting in Central Kalimantan.

Table 7. Carbon stocks of each carbon pool in each forest type (Mg C ha⁻¹)

Carbon pool	Forest Type					
	Dryland Forest		Peat Swamp Forest		Mangrove Forest	
	Primary	Secondary	Primary	Secondary	Primary	Secondary
AGB (DBH ≥10cm)	138	100	75	62	104	62
AGB (DBH <10 cm; H >1.5m)	10	6	33	30		
Understorey (H < 1.5m)	1	3	3	4	nd	nd
BGB (Roots)	43	32	24	21	8	7
Litter	5	4	2	2	nd	nd
Woody debris	25	33	20	22	50	46
Total C-stock	222	178	157	140	162	116

Note: nd = no data

The amount of carbon stocks can be used to quantify the amount of carbon dioxide (CO₂-e) that could be released to the atmosphere due to clearing or deforestation event by converting these values to CO₂-e (multiplying with a factor of 44/12). Referring to Table 7, the total values of carbon stocks in each forest type are equivalent to the carbon dioxide in the atmosphere of 814 Mg CO₂-e ha⁻¹ in primary dryland forest, 653 CO₂-e ha⁻¹ in secondary dryland forest, 576 Mg CO₂-e ha⁻¹ in primary swamp forest, 513 CO₂-e ha⁻¹ in secondary swamp forest, 594 CO₂-e ha⁻¹ in primary mangrove forest and 425 CO₂-e ha⁻¹ in secondary mangrove forest, respectively.



4. Discussion

The amount of biomass and carbon stored in forest ecosystems varies greatly between forest type and forest condition (Tables 2-6). Among the four pools of carbon studied (excluding soil organic matter), the aboveground biomass pool represents the largest proportion of the total biomass, ranging from 53.6% to 70.6% (Figure 3). Trees (DBH \geq 10 cm) represent the largest single component of the total biomass, ranging from 44% to 65%. Variation in this proportion may be related to species composition, which influences wood density, particularly the density of large trees with high wood volumes.

Secondary forests have less carbon stored in forest biomass compared with primary forest (undisturbed forest condition) (Table 7). The estimates of carbon loss stored in the four pools following disturbances in secondary forests is about 20% in dryland forest, 11% in swamp forest and 28% in mangrove forest, compared with primary (undisturbed) forest. A study by Hardiansyah (2011) in dryland logged-over forest in Central Kalimantan (several years after logging) have shown 30-65% less carbon compared with primary forest. In selectively logged-over forest in Gabon with reduced impact logging (RIL) techniques, aboveground forest biomass declined by only 8% (Medjibe et al., 2011). Another study in selectively logged-over forest in Papua New Guinea, aboveground forest biomass declined up to 31% (Bryan et al., 2010). However, it should be noted that the loss of carbon in secondary forests does not necessarily reflect the loss of carbon due to harvesting at a point in time, but it is the effect of years of logging on the carbon stocks of the entire forest. Reductions in forest C-stocks (quantity of carbon loss from the forests

and released to the atmosphere) resulting from the disturbance process should be identified based on the level and type of disturbance (e.g. secondary forests due to conventional selective logging practice will have a different impact on carbon with the secondary forests resulted from reduced impact logging practice).

Woody debris (including fallen and standing dead trees) is a significant component in some forest types, particularly in secondary forest following disturbance. This pool constitutes 11% to 40% of total ecosystem biomass (Figure 3). The proportion of 10% to 40% of aboveground biomass was also reported in previous studies (Uhl and Kauffman, 1990; Verwer and Van der Meer, 2010). The proportion of woody debris mass in secondary (disturbed) forests is higher than in primary forests. Palace et al (2007; 2008) found that selectively harvested forest in the Amazon had 50% more woody debris than undisturbed forest. The disturbances affect biomass by moving carbon from an aboveground biomass pool to a woody debris pool as more residual material is left after disturbance. This pool can serve as a long-term carbon pool (Brown and Lugo, 1992).

The proportion of litter to total biomass in forest ecosystems is generally small (1 to 2%) (Figure 3). The proportion tends to be higher in secondary forest (dryland and swamp forests) than in primary forest, which is dynamically related to forest productivity and disturbance history. In mature forest the annual rates of production tend to be balanced by decomposition with no significant accumulation (Brown and Lugo, 1992). In mangrove forest, estimation of biomass for this component is particularly difficult and litter is usually not included as most mangroves have little to no litter, contributing negligible carbon pool (Snedaker and Lahmann, 1988).

The contribution of understorey vegetation to aboveground biomass is small but variable, 4% or less in this study (Figure 3). Regardless of the small contribution to total biomass, this should be included for accurate estimates of aboveground biomass. The contribution is likely to be larger in secondary forests than in primary forests. In secondary forests, abundant understorey vegetation is generally interpreted as a sign of past forest disturbance and subsequent recovery.

The belowground biomass (roots) varies considerably across forest ecosystem types contributing to 5% to 20% of the total ecosystem biomass (Figure 3). The amount of belowground biomass is most likely to be a function of soil type, soil fertility and moisture regime (Brown and Lugo, 1992).

The aboveground tree biomass (DBH \geq 10 cm) stores the largest quantity of carbon in the forest ecosystems of Central Kalimantan. However, considering this pool only (e.g. based on forest inventories which often report timber stocks with a minimum DBH of 10 cm) and ignoring the other pools of aboveground trees (DBH < 10 cm), will lead to an underestimate of the amount of biomass and carbon stored in the ecosystem. Including other components is therefore critical for carbon accounting as the traditional forest inventories (DBH \geq 10 cm) only include 44% to 65% of the total biomass in our study.

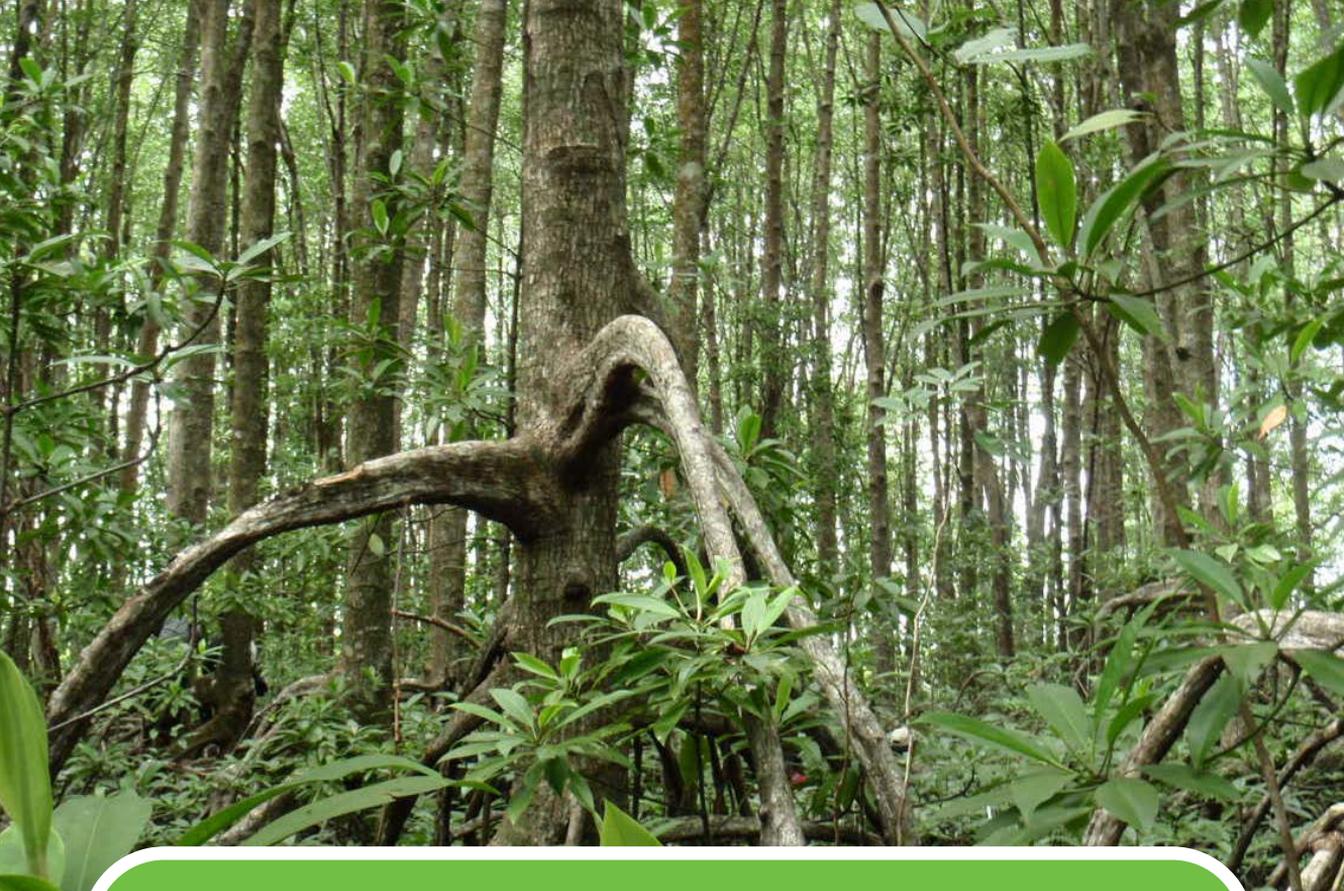
Although thousands of inventory plots have been established across Central Kalimantan forests and used in the analysis of biomass, they are distributed mainly in dryland and swamp forests. No inventory plots have been established in mangrove forest in Central Kalimantan. However, the area of mangrove forest in Central Kalimantan is very small (0.3% of the total remaining natural forests) compared to other forest types. Regardless, establishing inventory plots to represent this mangrove forest type will be important to improve the estimates from mangrove forests, which is currently only based on a few research reports.

Most of the forest inventory data sources used in the analysis focused on the tree component of the forest and do not include biomass of non-tree vegetation (e.g. palm, rattan, bamboo, etc.) that may also be found in forests. Compared to aboveground biomass it is considered that the

contribution of non-tree vegetation in the forest ecosystem is generally small (Tanner, 1980; Brown and Lugo, 1992). Forest inventory typically excludes this component although its presence in the plots (if any) is usually recorded. Excluding this small pool of biomass does not lead to significant underestimates of the total biomass of forests.

The results of this study can be used in different approaches to carbon accounting of forests. The estimates can be converted to simple emissions factors where it is assumed that all carbon in each pool is emitted at the time of forest clearing. This approach has been used for estimating GHG (CO₂) emissions from deforestation for Central Kalimantan in a simple account as presented in Krisnawati et al. (2013). The results are also suitable for describing the initial forest condition for more comprehensive modeling of GHG emissions and removals from REDD+ activities, such as INCAS, where the change in carbon stock is modeled based on the impact of specific events.

The results of this study provide the basis to improve upon GHG emissions calculations previously reported (e.g. Jagau et al., 2012; Agus et al., 2013). This improved approach includes analysis of emissions factors for forests generated from Central Kalimantan-based forest inventory plots data and the comprehensive approach used in generating forest biomass.



5. Conclusion and Recommendation

1. The amount of biomass and carbon stored in forest ecosystems varies between forest type and condition. Further analysis is needed to relate forest biomass and carbon stocks to other determining factors such as soil type, elevation, rainfall, as well as the proportions of biomass immediately emitted due to forest management activities and the portion of biomass decomposed over specified time intervals.
2. This study includes all components of carbon pools but excluding soil organic matter. Results of this study suggested that considering aboveground tree biomass pool only will understates the total biomass value of 44-65%. Additional research is needed to further improve estimates of biomass for all forest components at the accuracy and scale necessary for landscape level analysis of each forest type in Central Kalimantan.
3. The results of this study provide the basis for improvement upon GHG emissions calculations previously reported. This can be used to assist Central Kalimantan move toward a Tier 3 compliant GHG inventory of forest land. The methods and analysis used are also relevant and replicable to other provinces and for the national level, which are able to support the development of a credible MRV system.

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Annex 1. Description of datasets for each forest inventory plot

National Forest Inventory (NFI) data – The NFI is a national program initiated by the Ministry of Forestry in 1989 (and implemented by the Directorate General of Forestry Planning) through the NFI Project with the assistance of the Food and Agriculture Organization of the United Nations (FAO) and the World Bank. The program has been designed for two major purposes: (1) to develop an in-house capability for the Ministry of Forestry to undertake continuous forest inventory activities, and (2) to generate forest resource information for policy formulation and strategic planning at the national and provincial levels. Since commencing, about 2,735 re-locatable 1 ha plots (permanent sample plots – PSP) on a 20 x 20 km grid across the country and a cluster of temporary plots surrounding each PSP (temporary sample plots – TSP) have been established systematically across Indonesia. More than 200 NFI plots are located in Central Kalimantan. The majority of the plots were established in areas below 1000 m altitude. The first phase of measurements was conducted in the period of 1989-1996 with extensive forest resource statistics reported in 1996¹. Among these statistics is information on the numbers of trees by species and size class, by provinces and groups.

Individual trees within the 1 ha PSP are measured within 16 numbered 25 x 25 m sub-plots. A point sample of trees within the PSP is also located with azimuth and distance from the plot centre; these individual trees can be reliably relocated during future measurements, while the remaining trees can only be regrouped into their $\frac{1}{16}$ ha sub-plot. All trees with a minimum diameter of 5 cm were measured for DBH, and a sub-set measured for total tree height. Trees were also classified by local species name, crown characteristics, damage, and infestation. Site information, including observations on disturbance and regeneration, and non-tree data (bamboo, rattan, etc) was also recorded. The plots are classified under a range of types/conditions which include land system, altitude in 100 m class, land use, forest type, stand condition and plantation status, terrain, slope, and aspect. The protocols used in field sampling and system design for plot data processing for the NFI in Indonesia are described in Revilla (1992)².

The second phase of measurement was conducted during the period of 1996-2000, and the third measurements were carried out in 2000-2006. About 40% of the plots measured in the first phase were measured in the second phase. From these, only about 35% were further measured during the third phase. Remeasurement, quality assurance and refinement of the NFI PSP data are ongoing. Despite the incomplete remeasurement of the entire PSPs, analysis of the existing NFI database can provide substantial information for estimating forest biomass and supporting the development of growth and yield models and otherwise support good forest management in Indonesia.

Periodical Comprehensive Forest Inventory (PCFI) data – PCFI or, as called in Indonesia, *Inventarisasi Hutan Menyeluruh Berkala* (IHMB), is also a national program initiated by the Ministry of Forestry in 2009 (implemented by the Directorate General of Forestry Production Development) through the Forestry Ministerial Regulation No. P.33/Menhut-II/2009. The

¹National Forest Inventory of Indonesia: Final Forest Resources Statistics Report. Report to the Directorate General of Forest Inventory and Land Use Planning Ministry of Forestry, Government of Indonesia. Field Document 55, UTF/INS/066/INS Food and Agriculture Organisation of the United Nations. Jakarta, June, 1996.

²Revilla, J.A.V. 1992. Step-by-Step Field Sampling Procedures for the NFI Project. Indonesia UTF/INS/066/INS National Forest Inventory Working Document No. 3. Food and Agriculture Organisation of the United Nations. Jakarta.

purposes of the program are: (1) to measure timber standing stocks of production forests in Indonesia for both natural forest and planted forest, (2) to generate the basis of information for developing a 10-year periodical workplan of the Forest Management Units (FMUs), particularly in formulating yield regulation to ensure sustainable forest management, and (3) to monitor trends in the sustainable timber standing stock in the FMUs. All FMUs need to conduct inventories in all compartments of the production forests, periodically in a 10 year period. In each compartment (covering an area of 100 ha) of the FMU, one inventory plot is established. The plot shape in natural forest is rectangular with an area of 0.25 ha (20 m x 125 m), while in plantation forest circular shapes of various sizes are used depending on the age (age classes) of the plantation. A total of 16 FMUs in Central Kalimantan have conducted PCFI which resulted in the establishment of 10,514 inventory plots. Unlike with the NFI data, which measured trees with DBH \geq 5 cm, in PCFI plots all trees with a DBH \geq 10 cm are measured and total tree height is measured for a subset of trees, with the local tree species name are recorded.

The procedures used in plot establishment and measurement followed the Guidelines of the Periodical Comprehensive Forest Inventory for Timber Utilization in the Production Forests (the Forestry Ministerial Regulation No. P.33/Menhut-II/2009 jo P.5/Menhut-II/2011).

These data are used as a foundation in the preparation of management plans for harvesting in sustainable production forest management. The data can also be used to analyze aboveground carbon stock potential in tree biomass and forest stand.

Permanent Measurement Plots (PMPs) data. – PMPs or, *Petak Ukur Permanen (PUP)*, are part of a national program initiated by the Ministry of Forestry in 1995 through the Forestry Ministerial Decree No. 237/Kpts-II/1995. Through this program, all logging concession companies were requested to establish PMPs for monitoring growth and yield in the logged-over forests in Indonesia. The guideline for plot establishment and measurement was prepared by the Forestry Research and Development Agency (FORDA) through the Director General of FORDA's decree No. 38/KPTS/VIII-HM.3/93.

The PMPs were classified into two major forest types, i.e. dryland forest and swamp forest. The plots were established in a logged-over area 1 to 3 years after logging in the production forests of each FMU. For dryland forest, a minimum number of PMPs needs to be established in a series of five-year management plan area is 6 plots and, for swamp forest, the minimum number is 16 plots in one FMU. The PMP is square in shape with a minimum horizontal distance of 200 m x 200 m. In each PMP an observation plot sized 100 m x 100 m is established where the diameter and height of all trees \geq 10 cm in diameter are measured, and their species are identified. The results of measurement and observation conducted is reported to the Directorate General of the Forestry Production Development and the Directorate General of Forestry Research and Development, and used to obtain information on forest growth and stand productivity. The data can be used for calculating the potential and growth (dynamics) of aboveground biomass or carbon of trees (DBH of 10 cm and above).

KFCP (Kalimantan Forests and Climate Partnership) vegetation monitoring data. KFCP is a REDD+ demonstration initiative developed in 2008, funded by the Australian Government and implemented through the Indonesia-Australia Forest Carbon Partnership (IAFCP). A series of Forest Monitoring Plots (FMP) in a range of selected locations across the KFCP study site were established to facilitate calculation and description of biomass, forest structure and composition, and rates of regeneration. Eight locations were selected as representative of the forest types spread throughout the study site, based on previous ecological and forestry studies conducted in the area (BOS-Mawas KFCP Report Phase II, Wetlands KFCP Report on Land Cover Assessment,

Master Plan KFCP Strategic Peatland Rehabilitation Plan). The locations represent an area of forested in deep-peat, forested with canal-disturbed in deep-peat, disturbed forest with deep peat compartment, disturbed forest in mid-depth peat, non-forested with shallow-peat compartment, and forest burnt in 2009.

Plots were designed following a 'nested plot' design. The plot shape is square, 32m x 32m for tree (DBH > 20cm), 16m x 16m for pole (20 cm > DBH > 10 cm), 8m x 8m for sapling (10 cm > DBH, height > 1.5 m) and 2m x 2m for seedling (height < 1.5 m). Five from 8 locations are associated with canals, three transects were established in each location that ran perpendicular to the canal and parallel to the hydrology transects, transects spaced 150 m. Along each transect, four plots were established, at 50 m, 100 m, 400 m and 700 m from the canal, thus reaching near to the center of each compartment. Three locations were not associated with canals. Three transects were established at each location, these were positioned along the hydrology transect and spaced at 150 m. These locations represent different sections of the relatively undisturbed, closed-canopy forest. Each plot received a unique code based on its location, transect number and plot number. All methods were designed to follow the measurement and calculation of carbon stocks following the guideline of 'Field Measurement for estimating forest carbon stocks (ground based forest carbon accounting)' (SNI 7724, 2011).

Each individual plant was tagged with a unique number before measuring the DBH point and the height to the top of each individual plant. Seedlings were not measured for DBH, only height. The species were recorded in the field, or for unknown species, a morphological characteristics of the species were recorded and sample taken for identification. Detailed description of the vegetation monitoring plots can be found in the KFCP technical paper³.

³Graham, L. and Mahyudi, A. Vegetation monitoring methodology. Kalimantan Forests and Climate Partnership (KFCP) Technical Paper.



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